3.0 NUMERIC TARGETS

As stated by Novotny and Olem (1994, 243), "…it is unrealistic to expect or require complete control or elimination of sediment loads to receiving waters. Such "wall-to-wall control measures would be technically and economically impossible." The authors then state that "…it is feasible to control or manage excessive sediment loadings that have resulted from man's land use activities that would be detrimental to the quality of the receiving bodies of water and to the aquatic and terrestrial habitat." Pursuant to federal TMDL requirements, quantifiable and measurable numeric targets that will ensure compliance with water quality standards (including beneficial uses and water quality objectives) must be established in a TMDL (USEPA 1999b).

The TMDLs and numeric targets for Big Bear Lake and Rathbun Creek must be structured to guarantee protection of the MUN, COLD, WARM, WILD, REC1, and REC2 beneficial uses and attainment of the sediment-related water quality objectives specified in the Basin Plan (see Section 2.1). In addition, the TMDL and numeric targets for Big Bear Lake must also ensure protection of Bear Creek, downstream of the lake.

Numeric targets that are proposed for Big Bear Lake include those related directly to sedimentation/siltation, as well as those that provide a means to track the overall improvement in the health of the lake and the watershed. The proposed numeric targets for Big Bear Lake represent desired conditions of lake capacity that would result in improvement in aquatic habitat and recreational beneficial uses. Similarly, the proposed numeric targets for Rathbun Creek are related directly to sedimentation/siltation and include indicators of the overall improvement in stream health.

To establish the numeric targets, Regional Board staff first considered use of established narrative and numeric sediment objectives. As discussed in Section 2.1, the Basin Plan specifies narrative and numeric water quality objectives for suspended solids and turbidity, respectively, for Big Bear Lake and Rathbun Creek. Turbidity could be used as a numeric target, but it appears that for the most part, turbidity in Big Bear Lake is due to algae and not inorganic particulates (see nonalgal turbidity discussion, page 36). For this reason, it was determined that turbidity would not be an adequate or appropriate numeric target in assessing sedimentation/siltation for Big Bear Lake. However, a turbidity numeric target for Rathbun Creek appears to be reasonable because about 75% of the TSS concentration is attributed to inorganic sources. Because the suspended solids water quality objective is a narrative one, it is necessary to identify some numeric expression of compliance, which serves as the requisite numeric target. Comparison of TSS data from reference streams or watersheds to data from the listed body of water is often utilized. However, in this case, there are no TSS data from reference streams or watersheds in the Santa Ana Region similar to the Big Bear Lake watershed that could be used for comparison to impaired conditions. Creeks such as Boulder, Metcalf and Grout could serve as potential reference creeks for the watershed, however, a detailed reference creek survey is a prerequisite. As part of the implementation plan, future monitoring in this watershed is proposed and the relationship between TSS concentrations and reference conditions might be quantified.

Regional Board staff evaluated other alternatives to select both water quality indicators and target values. A regression analysis could be developed for turbidity and TSS. Using the regression equation, the TSS value could be predicted from a known turbidity value. This approach is often used and results in better relationships than those between suspended sediment concentration and discharge (Thomas 1985). However, paired datasets of turbidity and suspended sediment concentration are needed and these data were not available for this TMDL. In addition, as discussed above, turbidity does not appear to be a useful indicator for the Big Bear Lake sedimentation/siltation problem.

The USEPA protocol for developing sediment TMDLs acknowledges that erosion is a natural process and that it is difficult to separate sediment produced from natural conditions from sediment produced from disturbed conditions (USEPA 1999b). In addition, sediment production rates vary considerably from year to year. The protocol also mentions that relating sediment mass loading levels to beneficial use impacts or source contributions is difficult because sediment yields vary at different spatial and temporal scales and therefore quantifying "average" conditions is difficult. The USEPA protocol mentions other alternative approaches to mass loads in expressing sediment TMDLs, such as expressing numeric targets related to substrate or channel condition, aquatic biological conditions, or hillslope indicators. USEPA (1999b) encourages using multiple numeric targets and a "weight of evidence" approach, meaning that indicators would be evaluated as a whole and if one target was not met, it would not necessarily imply that the TMDL is not working.

For Big Bear Lake in particular, consideration of such an alternative TMDL approach is appropriate. In part this is because of the lack of relevant data on which to base suitable numeric targets. The more important reason pertains to the nature of the lake itself. As described in Section 1.0, the lake is artificial, having been created by the construction of the dam in 1883-84. As discussed in the next Section (Source Assessment), most of the sediment entering the lake appears to come from natural sources in the watershed and results from erosion and sediment transport during storm events[21]. Consistent with the principles of ecological succession, without human intervention, the lake would naturally fill-in over time and be restored as a meadow habitat. The reality, however, is that Big Bear Lake is an ecological and recreational resource of statewide significance, and its continued existence is necessary to support the local economy, as well as these beneficial uses. Accordingly, it is appropriate to define numeric targets and TMDLs that recognize the unique nature of the lake, the largely natural sources of sediment loading, and the need for active and coordinated management of the lake to assure that beneficial uses are protected. With respect to sediment, management of the lake can be expressed in terms of improvement of lake capacity, tied to specific and coordinated plans to manage aquatic plant nuisance growth and to create and enhance fisheries and other wildlife habitat.

While, as noted, much of the sediment loading to the lake results from natural sources during wet weather, human-induced activities have likely contributed to the erosion problem (see Section 4.0, Source Assessment). For example, sediment loads might be increasing in lower parts of tributaries due to the degradation and scour caused by increased flood flows resulting from urbanization (Humphrey 2003a; Humphrey 2003b). It is appropriate to require the implementation of BMPs to reduce such sediment loading to the maximum extent practicable. Accordingly, a sediment load numeric target is also proposed for the Big Bear Lake TMDL. This numeric target was developed based on the HSPF model results (see Section 4.0).

[21] A draft report prepared by Dr. Matthew Kirby titled "Determination of sedimentation rate and sedimentation processes at Big Bear Lake: Using a paleo-perspective to understand modern sedimentary systems" discusses the dominant sedimentation processes (Kirby 2005). In this document, the author hypothesizes that as lake levels decrease for prolonged periods, sedimentation actually increases and is more important to the overall sedimentation rate than local runoff during storms and snowmelt. This statement is in direct conflict with information reported in the report prepared by BBMWD, Hydmet, Inc., and AquAeTer, Inc. 2003. More studies are needed to fully identify the dominant process or processes responsible for the majority of the sediment loads to Big Bear Lake.

Similarly, a proposed numeric target for Rathbun Creek is directly related to the biological health of the creek and the desired environmental conditions. A sediment load target is based on the HSPF model results, and the second proposed target is based on the Basin Plan objectives for turbidity.

It is recognized that much more data are needed to refine the proposed numeric targets and to consider the application of other targets, such as hillslope indicators. The proposed TMDLs are phased to allow for such data collection and refinement, and the proposed Implementation Plan (Section 9.0) includes specific, pertinent monitoring requirements.

The following sections describe the proposed numeric targets in greater detail.

3.1 Big Bear Lake Sediment Numeric Targets

Proposed numeric targets for Big Bear Lake are shown in Table 3-1. Total sediment load is proposed as a numeric target. Additional investigation of the water quality measures needed to achieve the total sediment load target is likely to be necessary. Thus, a schedule for compliance no later than 2020 is proposed. The other proposed numeric target is for a 5% improvement in lake capacity to be achieved no later than ten years from the effective date of the TMDL. Related to this target is a requirement in the proposed implementation plan for the development and implementation of an approved lake management plan and in 3 years to reevaluate the numeric target (see Section 9.0, Implementation Plan). This plan would integrate sediment management with biological and recreational resource management to assure the protection of beneficial uses. It also needs to integrate plans developed and implemented to address eutrophication in the lake (see Big Bear Lake Nutrient TMDL staff report, June 1, 2005). It is expected that the lake management plan will, in part, define optimal future lake capacity conditions and the control measures needed to achieve them. The plan must necessarily take a watershed view and address control and management of sediment inputs from Rathbun Creek and other tributaries. Restoration/protection of the beneficial uses of the tributaries to the lake, as well as Bear Creek, downstream from the lake, must also be addressed. Approved numeric targets and TMDLs for both Big Bear Lake and Rathbun Creek will be revised as appropriate to reflect the approved lake management plan and the desired environmental conditions identified therein.

Derivation of the Big Bear Lake proposed targets is discussed below.

3.1.1 Sediment Load

Numeric Target

The proposed target for sediment is 12,000 tons sediment per year and is based on the sediment load from forested lands that would be expected under natural conditions (i.e, no anthropogenic activities that would affect erosion and sedimentation). The Big Bear Lake watershed is comprised of 11,690 acres of north facing slopes and 8,899 acres of south facing slopes. The sum of the area of these two aspects is 20,589 acres, excluding the lake area[22]. To calculate an average natural background load, the sediment loading rates for both the north and south forest

[22] Note that there is a discrepancy between this total land area and the watershed area as shown in Table 1-2. This is due to slight differences in the GIS layers that were provided as part of the HSPF watershed model.

land uses (0.36 tons/acre/yr and 0.86 tons/acre/year, respectively, were multiplied by the acres of north and south facing slope areas in the watershed. These loading rates assume that all lands with the forested areas are not impacted by human activities. The result of the calculation is 11,862 tons/year of sediment delivered by forested land for the entire watershed area. This figure was rounded to 12,000 (two significant figures)[23]. This numeric target assumes that erosion/sedimentation caused by anthropogenic activities can and will be controlled to the maximum extent practicable. Where it is infeasible to achieve the wasteload and/or load allocations based on this target (see Section 6.0), in-lake sediment removal/control programs can be implemented such that the net effect is compliance with the allocations and numeric target.

Board staff recognizes the limitations in using sediment loads as a numeric target, i.e., variability of sediment production rates from year to year, and difficulties in relating sediment mass loadings to beneficial use impacts. To address these limitations and take into account the inherent variability in sediment loading, the numeric target is proposed as a 10-year running average[24]. In addition, as stated previously, the proposed TMDLs are based on a phased approach, which means that as new data are collected and analyzed, the numeric targets, allocations and TMDLs themselves will be reviewed and revised, if necessary.

The monitoring programs proposed as part of the implementation plan for this TMDL will aid in the development of a comprehensive sediment budget for this watershed (see Section 10.0). Because it is impractical to monitor all inputs to the lake, compliance with the target value will be determined from flow, suspended sediment and bedload concentration data collected at five key tributaries (Rathbun Creek, Minnelusa Canyon Creek, Knickerbocker Creek, Boulder Creek and Grout Creek). If these creeks and/or methodology are not suitable for this determination, alternatives can be provided. These data will be used to extrapolate loads from the remainder of the watershed to determine the total sediment loads to the lake.

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[23] It is recognized that there are roads, campgrounds, mountain bike trails, fire reduction programs and programs to remove dead trees (resulting from bark beetle infestation and drought conditions in the watershed), and that these facilities/ activities likely affect erosion and sedimentation in the watershed and lake. No data are currently available on the extent of these facilities/activities and their sediment-related effects.

[24] Staff believes that use of a 10-year running average is a reasonable approach. It allows adequate time for collecting new data on sources of sediment and sediment yields, along with implementing, monitoring and assessing BMPs. The data collected are to be used in a new modeling effort. During this time, the 10-year running average approach can be reevaluated with respect to the newly collected data and the new model scenarios.

Table 3-1. Proposed numeric targets and indicators for the Big Bear Lake sediment TMDL

Indicator	Target Value[c]	Reference
Total Sediment Load [a]	Annual average of 12,000 tons/year as a 10-yr running average; to be attained no later than 2020	HSPF modeling (BBMWD, Hydmet, Inc., and AquAeTer, Inc. 2003; Hydmet 2004)
Lake capacity[b]	A 5% improvement in lake capacity in 10 years[d]	NA

[a] source targets related to load allocations/waste load allocations (see Section 5.0)
[b] monitoring target that will not be used for load allocations/waste load allocations
[c] compliance with the targets to be achieved as soon as possible, but no later than the date specified
[d] see also Section 9.0, Implementation Plan

3.1.2 Lake capacity

According to BBMWD (2002), the lake capacity in 1912 was 137,105,000 cubic yards, or 85,000 af. In 1977, the lake was resurveyed and the lake capacity had decreased to 116,942,500 cubic yards, or 72,500 af, a 15% decline over the 65-year period. The difference between these two volumes is 20,162,500 cubic yards, or roughly 20 million cubic yards. With stakeholder input, it was determined that it was not feasible to remove this amount of sediment from the lake. As discussed in Sections 3.0 and 3.1, an alternative approach to management of the lake and protection of beneficial uses is recommended. The proposed numeric target is for a 5% improvement in lake capacity to be achieved as soon as possible but no later than 10 years from the effective date of the TMDL. It is expected that this numeric target will be revisited and likely revised and quantified once a lake management plan required by the proposed implementation plan is developed and approved. As stated previously, it is expected that this plan will include specific goals for lake capacity, coupled with management strategies intended to protect biological and recreational beneficial uses.

Because the lake is also on the Clean Water Act Section 303(d) list for nutrients, and bottom sediments contribute a significant portion of the nutrients through recycling, a costly, but effective, method of improving lake capacity would be dredging. Dredging would address not only the adverse beneficial use impacts caused by sedimentation and the creation of shallow areas in the lake but also would result in the removal of nutrients from the lake bottom that are currently recycled back into the water column. By deepening some shallow areas, resuspension of bottom sediments might be decreased, improving secchi disk transparency, lowering water column concentrations of nutrients, and improving aquatic habitat and recreational beneficial uses. Selective dredging strategies are likely to be an important element of the lake management plan required by the proposed implementation plan.

Numeric Target

The proposed numeric target is specified as a 5% improvement in lake capacity, to be achieved as soon as possible but no later than 10 years from the effective date of the TMDL. This target can be met through implementation of BMPs in the watershed and removal of sediment by selective dredging in areas with maximum sediment accumulation in accordance with the lake management plan[25]. For example, selective dredging of areas in which marinas and boat docks are located would protect recreational uses and hinder macrophyte growth (due to the greater depths). Reduced macrophyte growth would also reduce the need to harvest weeds or apply aquatic herbicides to these areas.

3.2 Rathbun Creek Sediment Numeric Targets

Proposed numeric targets for Rathbun Creek are shown in Table 3-2. Additional investigation of the water quality measures needed to achieve the numeric targets is likely to be necessary. Thus, a schedule for compliance no later than 2020 is proposed.
An average annual sediment load is proposed for Rathbun Creek as the primary numeric target. Indicators and targets for parameters other than the annual sediment load are also proposed in order to track improvements in the instream health of the creek. These additional indicators include turbidity and benthic macroinvertebrates. Board staff recognizes the limitations of using sediment loads as a numeric target, as discussed above for Big Bear Lake; however, the proposed target is expressed as a 10-year running average to mitigate the effects of spatial and temporal variability in sediment delivery rates. Moreover, the proposed TMDL is based on a phased approach, which means that as new data are collected and analyzed, load allocations and numeric targets will be reviewed and revised, if necessary.

Derivation of the Rathbun Creek proposed targets is discussed below.

3.2.1 Sediment Load

Numeric Target

The proposed target for sediment is 1900 tons sediment per year, measured at the mouth of Rathbun Creek (this figure is rounded to two significant figures). This proposed target was determined using the same approach as for Big Bear Lake. The Rathbun Creek watershed is comprised of 3154 acres of north facing slopes and 940 acres of south facing slopes. The sum of the area of these two aspects is 4094 acres[26]. To calculate an average natural background load, the sediment yields for both the north and south forest land uses (0.36 tons/acre/yr and 0.86 tons/acre/year, respectively) were multiplied by the acres of north and south facing slope areas in the watershed. This results in 1944 tons/year of sediment delivered by forested land for the entire watershed area. As for Big Bear Lake, these sediment yields assume that no anthropogenic activities in the watershed that affect erosion/sedimentation. This proposed numeric target is expressed as a 10-yr running average to minimize the effects of spatial and temporal differences in sediment delivery. Compliance with the target value will be based on measurements of flow, suspended sediment and bedload concentrations collected at the mouth of Rathbun Creek.

[25] Until the lake management plan is developed and approved, selection of appropriate dredging sites can be conducted in accordance with a beneficial uses map that is to be prepared as part of a Clean Water Act Section 401 water quality standards certification for the pilot dredging project at the east end of Big Bear Lake. This project is part of a Proposition 13 grant project. The beneficial uses map will designate areas of the lake with specific beneficial uses to aid in the selection of areas for improvement and enhancement of fisheries habitat and recreational access.
[26] Note that there is a discrepancy between this total land area and the watershed area as shown in Table 1-3. This is due to slight differences in the GIS layers that were provided as part of the HSPF watershed model.

3.2.2 Turbidity

Turbidity is a measure of light scattered due to particulates in water. Turbidity is affected by both inorganic and organic particulates. Although turbidity has not been monitored in Rathbun Creek, the ratios of VSS to TSS were evaluated. VSS is a measure of the organic fraction of TSS. For Rathbun Creek, the average contribution of organic sources was nearly 25%, meaning that 75% of the suspended solids are from inorganic sources. Turbidity thus appears to be a good indicator of impairment of beneficial uses caused by suspended sediment. Researchers have found reduced numbers and diversity of macroinvertebrates with turbidity values of 7-23 NTUs. This reduction is most likely due to reduced periphyton biomass resulting from light attenuation caused by the increase in turbidity (USEPA 2000, 33).

Numeric Target

The proposed numeric targets are the same as the Basin Plan objectives for turbidity.

“Increases in turbidity which result from controllable water quality factors shall comply with the following:

Natural Turbidity	Maximum Increase
0-50 NTU	20%
50-100 NTU	10 NTU
Greater than 100 NTU	10%

All inland surface waters of the region shall be free of changes in turbidity which adversely affect beneficial uses."

This indicator should be measured during storm flows, snowmelt and baseflow to measure the variability in turbidity values. In addition, measurement of levels upstream and downstream of management activities would enable the comparison of changes in turbidity levels due to those activities.

3.2.3 Benthic Macroinvertebrate Metrics

As noted above, benthic macroinvertebrate populations are affected by turbidity and serve as good indicators of changes in water quality. This indicator will be evaluated using the California Department of Fish and Game’s Stream Bioassessment Protocol (Ode, Rehn and May 2004). Sites within Rathbun Creek can then be compared to the SoCal IBI[27] and the predictive O/E[28] models being generated for the US Forest Service to evaluate watershed health. Together with physical and chemical parameters, biological assessment provides a third measure of overall stream health.

[27] The SoCal IBI is a macroinvertebrate-based assessment of biological integrity and is suitable for assessing biological integrity in wadeable streams and rivers for all of coastal California, from Monterey County to the Mexican border and inland to the borders of the Central Valley and the Mojave and Colorado deserts (Ode, Rehn, and May 2004).

[28] O/E is the ratio of observed to expected taxa (O/E). Values less than 1 indicate loss of taxa and biological impairment (Hawkins n.d.). This method of assessing the biological condition of streams is used primarily by the USFS.

Evaluations similar to the California Stream Bioassessment Protocol took place in October 2002 in Rathbun Creek, as well as in Big Bear Lake. However, at the time of the assessment there was no flow in the creek and the assessment was necessarily limited.

Numeric Target
Improving trends in the eight metrics specified for the SoCal IBI. These eight metrics are: Percent Collector-Gatherer + Collector-Filterer Individuals, Percent non-insect taxa, percent tolerant taxa, Coleoptera richness, predator richness, scraper richness, average tolerance value and EPT richness. Each metric is scored on a 0-10 scale, therefore, the SoCal IBI has a scoring range of 0-80, where 0 =very poor and 80 = very good.

Table 3-2. Proposed numeric targets and indicators for the Rathbun Creek sediment TMDL

Indicator	Target Value[c]	Reference
Total Sediment Load [a]	Annual average of 1900 tons/year as a 10-yr running average; to be attained no later than 2020	HSPF modeling (BBMWD, Hydmet, Inc., and AquAeTer, Inc. 2003; Hydmet 2004)
Turbidity[b]	Increases in turbidity which result from controllable water quality factors shall comply with the following: Natural Turbidity — Maximum Increase 0-50 NTU — 20% 50-100 NTU — 10 NTU Greater than 100 NTU — 10% To be attained no later than 2020	SARWQCB 1995
Benthic Macroinvertebrate Metrics[b]	Improving trends in 8 metrics as specified for the SoCal IBI[d]; to be attained no later than 2020	Ode, Rehn, and May 2004

[a] source targets related to load allocations/waste load allocations (see Section 5.0)
[b] monitoring targets that will not be used for load allocations/waste load allocations
[c] compliance with the targets to be achieved as soon as possible, but no later than the date specified
[d] SoCal IBI consists of 8 metrics (Percent Collector-Gatherer + Collector-Filterer Individuals, Percent non-insect taxa, percent tolerant taxa, Coleoptera richness, predator richness, scraper richness, average tolerance value and EPT richness). Each metric is scored on a 0-10 scale, therefore, the SoCal IBI has a scoring range of 0-80, where 0 =very poor and 80 = very good.

4.0 SOURCE ASSESSMENT

Current sources of sediment loading to Big Bear Lake and its tributaries were evaluated using computer modeling (i.e., HSPF watershed model) and direct load measurements. The HSPF model is used for the simulation of hydrology and water quality in watersheds, including sediment transport and movement of contaminants. The HSPF pervious sediment transport method was used to simulate sediment loads for the Big Bear Lake watershed from the pervious areas of the four land uses (forest, resort, residential, and high density urban)[29]. This sediment transport method addresses sediment produced by land surface erosion for pervious land segments only. To calculate the net sediment yield for a watershed, a sediment budget could be prepared that consists of the sum of sediment from overland flow and gully erosion, sediment from mass movements, and sediment from bank erosion, minus the sediment accumulated in major river channels. In most instances, the sediment yield from each of these processes is not known and is difficult to measure (Mount 1995, 118). These processes were not individually quantified for the Big Bear Lake watershed; instead a gross sediment load by land use was obtained from the watershed model. A more detailed source assessment will be carried out in 2005 and 2006 as part of a Proposition 13 grant. At that time, both hillslope and instream erosional processes and rates and potential control measures will be examined in greater detail (Reid and Dunne 1996, 5).

For more detailed information on the watershed modeling and external sediment source assessment, please refer to the nutrient budget report (BBMWD, Hydmet, Inc., and AquAeTer, Inc. 2003) and to the updated model runs (Hydmet, Inc. 2004), as well as information sent by Humphrey (2003). Note that all of the following graphs and tables for the flow and HSPF loads were created by Regional Board staff using data supplied by Hydmet, Inc (2004). The source assessment discussion below describes the sources of sediment and summarizes the sediment load estimates.

External nonpoint sources are grouped into general land use categories (forest and resort); point sources include urban runoff from high density urban and residential land use. The urban runoff category represents land uses that are within the City of Big Bear Lake and the County of San Bernardino. The urban discharges from these areas are regulated under NPDES permits issued to the San Bernardino County Flood Control District, the City of Big Bear Lake (as co-permittees) and Caltrans.

The major categories of sources that were evaluated in the Big Bear Lake watershed were:

- runoff from forest and resort land uses
- runoff from residential and high density urban land uses (hereafter described generically as urban runoff)

The HSPF model simulated streamflow, total suspended sediment and nutrients. The hydrologic component of the model used was calibrated to the monthly Big Bear Lake inflow by three independent procedures. These procedures included preparation of a lake water balance, conduct of a Plunge Creek regression and conduct of a Santa Ana River regression. Note that Plunge Creek, although in an adjacent watershed, has hydrology similar to the Big Bear Lake watershed and that the Santa Ana River gaging station located downstream of Big Bear Lake was used to calibrate the outflow at Big Bear Lake. These procedures had to be used to simulate flows since there are currently no gaging stations in the Big Bear Lake watershed and, again, there are few

[29] Refer to Section 1.1, p. 19 for a description of the land uses.

flow data available for the watershed. The water quality component of the model simulated total nitrogen, total phosphorus, total kjeldahl nitrogen (TKN), nitrate, nitrite, orthophosphate and ammonia, while the sediment component of the model simulated total suspended sediment. One of the limitations of the simulations with the HSPF model is that the hydrologic events that were sampled for calibration purposes were of low intensity and consisted of rainfall/snowmelt in dry years that could not be extrapolated to average precipitation or wet years. As a result, fits between the simulated and observed flows for calibration purposes were within 10% for annual runoff and 20% for monthly runoff. These results were considered sufficient due to the fact that there were few local tributary inflow data, and the only recorded precipitation data records were near the lakeshore, with no records of higher elevation precipitation or snow cover.

HSPF model calibrations for external sediment loads based on Big Bear Lake watershed data were not performed since the existing observed data were not adequate for this purpose (BBMWD, Hydmet, Inc., and AquAeTer, Inc. 2003)[30]. However, the model was calibrated by using the accumulated sediment load in the Rathbun Creek sediment basins and dividing by ten years (i.e., the period of record for the sediment basins) (Table 4-1). This number was then multiplied by the ratio of the entire area of the Big Bear Lake watershed to that of the Rathbun Creek watershed and adjusted for the perceived higher sedimentation rates from Rathbun Creek compared to other tributary watersheds. The estimate was 10,000 to 20,000 tons of sediment per year. The HSPF model was set up with parameters in the sediment detachment and removal equations to produce an average annual load of 10,000 tons. Wet year HSPF sediment concentrations (e.g., 1993) were comparable to flood events monitored in Lake Tahoe and to the flood event methods used by the U.S. Army Corps of Engineers Los Angeles District for Southern California (Humphrey 2003a; Humphrey 2003b).

As part of the phased TMDL approach, additional sediment water quality and flow data collected during higher intensity rainfall and snowmelt and data collected from a high elevation weather station (proposed for installation) will be used to calibrate the water quality and sediment components of the HSPF watershed model.

[30] Weirs and flow meters installed in 2002 at key locations within the watershed were used to sample stormwater and record flows. However, much more flow and load data needs to be collected before there will be an accurate understanding of the duration, magnitude and type of flow (e.g., baseflow, storm events or snowmelt) that delivers sediment to the lake.

Table 4-1. Sediment detention basins within the Rathbun Creek subwatershed

Name	Location	Approximate Size lxwxd (in feet)	Approximate Capacity (cubic yards)	Clean out method/frequency	Material Disposal	Impacts
Station A	500 feet south of Big Bear Lake in Rathbun Creek	400x40x15	2500	Dragline/once every 2 years	Moved from basin and set to the west of the basin and allowed to dry for 1 year. Silt fence surrounds the material while drying. Then used by a contractor for topsoil.	Willows are trimmed back for access.
Station B	25 feet south of Elm Street, next to Bear Mtn.'s lower parking lot, in Rathbun Creek in lower Moonridge. There is a concrete check dam.	35x35x2	--	Backhoe or excavator/once a year in the fall after creek stops flowing	Removed from site and loaded on trucks and hauled off-site	Willows are trimmed back for access
Station C	Located between Station B and Station D south of Elm Street and north of Moonridge Road	30x20	--	Backhoe or excavator	Removed from site and loaded on trucks and hauled off-site	Willows are trimmed back for access
Station D	1000 feet north of Moonridge Road, next to Bear Mtn.'s lower paking lot in Rathbun Creek in lower Moonridge. It has a concrete check dam.	45x30x2	--	Backhoe or excavator	Removed from site and loaded on trucks and hauled off-site	Minimal vegetation disturbance
BBMWD 1	Lake bottom at the mouth of Rathbun Creek	--	9000	Backhoe or excavator/2-3 years	--	--
BBMWD 2	Rathbun Creek near the trout farm	--	500	--	--	--

Note: Data obtained from 401 Waiver issued by SARWQCB on 3/25/1998 and by personal communication with Gene Martin, BBMWD's Lake Manager (2003).
-- = data not provided
For a 10-year period (1993-2003), approximately 10,000 cubic yards of sediment were removed at the mouth of Rathbun Creek (Martin 2003).

Fourteen water years, 1990-2003, are simulated by the model. ***The proposed TMDLs are based on the average of all loads from the period of record of 1990 to 2003. This period incorporates loads from wet, dry, and average hydrological periods.***

The Watershed Database Management (WDM) file consists of all the meteorological time series data used for the hydrology simulation of the HSPF model and was assembled for the time period of October 1948 to December 2002 (54 years). HSPF accesses WDM files for both input and output time series data. The WDM file was extended through December 2003 for the WASP modeling effort conducted by Tetra Tech in 2004[31]. Because hourly precipitation data were not available or published for any location in the San Bernardino Mountains before October 1948, model simulations prior to 1948 were not possible (BBMWD, Hydmet, Inc., and AquAeTer, Inc. 2003).

The GIS data assembled and used to characterize the Big Bear Lake watershed consisted of subbasins, mean annual precipitation, elevation/aspect, land use, and soils. The datasets contained the following attributes: 1) four land uses (forest, resort, residential, and high density urban); 2) two elevation zones (>7,500 ft and <7,500 ft); 3) two aspects (land oriented facing north or facing south); 4) four precipitation zones (15-20", 20-25", 25-30", and 30-35"); and 5) two dominant soil types (low and high water holding capacity). By combining the GIS datasets, a total of 128 types of pervious surfaces (PERLND in the HSPF model) were obtained. Ultimately, only 30 pervious land use types were used to define all the possible combinations of the variables. The other combination types simply were not present or had areas that were less than 10 acres. Eight impervious land use types were used in the Big Bear Lake watershed model (BBMWD, Hydmet, Inc., and AquAeTer, Inc. 2003).

The surface area of the lake was estimated at approximately 2,282 acres. Based on the bathymetry provided by ReMetrix in 2001, the surface area of the lake at full pool (i.e., at a lake elevation of 6,743.2 ft.) was determined to be 2,808 acres, with a corresponding volume of 72,696 af (compare to Table 1-1) (BBMWD, Hydmet, Inc., and AquAeTer, Inc. 2003). The lake has lost storage capacity since the original gage height-lake capacity chart was created in 1977. These updated values, based on the newest bathymetry obtained in 2000, were used in the HSPF model.

Hydrology of the Big Bear Lake Watershed

The summary of HSPF simulated inflows for the period of record 1990 to 2003 around the average total flow shows that 1993 was the wettest year during this period (Figure 4-1). In fact, out of the entire 14-year period, there were only 3 years with flow above the average total flow of 14,032 AF (1993, 1995 and 1998). The majority of the years are below the average total flow. Low-flow conditions typically occur from July through October, with the minimum monthly average simulated flow of 34.7 AF recorded during August (Figure 4-2).

[31] Discussed in the Big Bear Lake Nutrient TMDLs staff report, June 1, 2005.

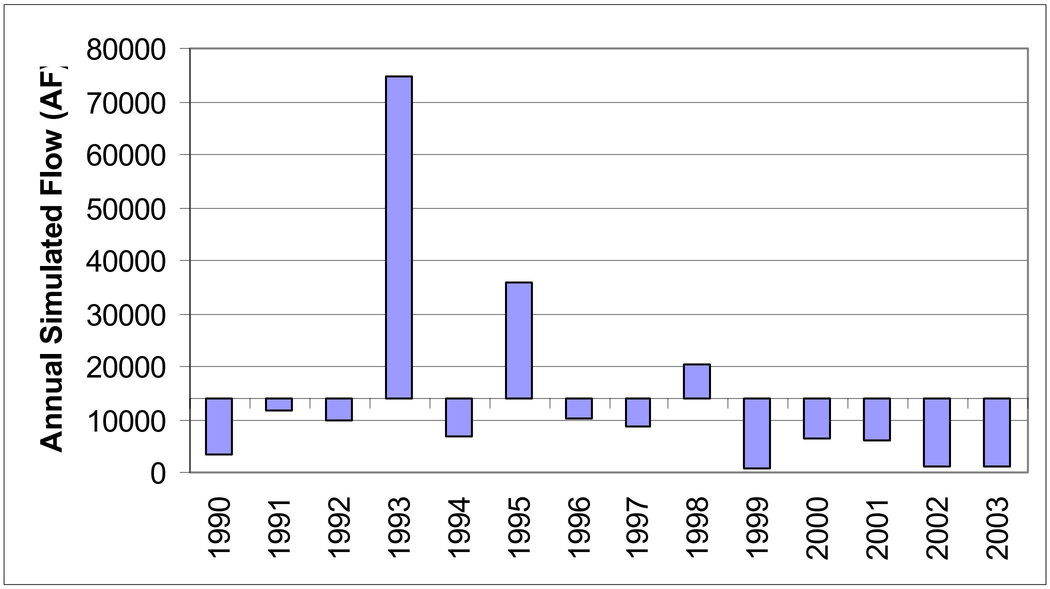

Figure 4-1: Variation of annual total flow (AF) from HSPF model land uses around average total flow (AF) for the period of record 1990-2003 (CY)

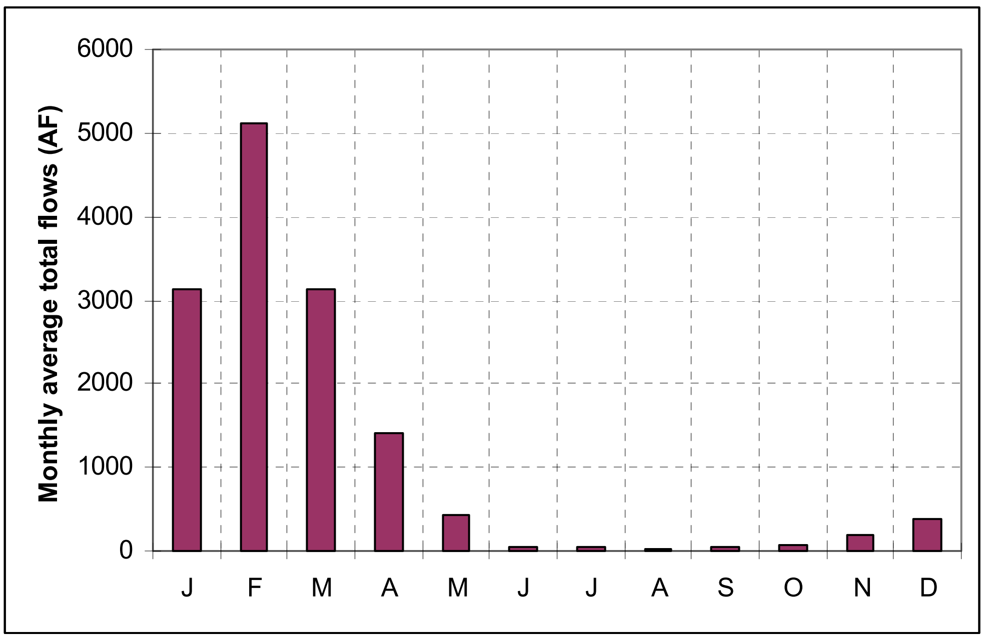

Figure 4-2: Monthly trends of average total flow (AF) for Big Bear Lake, 1990-2003 (CY)

Hydrology of the Rathbun Creek subwatershed

Shown in Figures 4-3 and 4-4 are the total annual simulated flows and average monthly simulated flows in AF for Rathbun Creek. The wettest year for the 14-year period of record (1990-2003) was 1993. The majority of the flows occur during the winter, with February contributing the greatest flows (Figure 4-4). For the past few years, runoff due to precipitation and snowmelt have been the lowest in years. Rathbun Creek has only been sampled on a few occasions due to lack of flow. Rathbun Creek comprises approximately 18% of the total Big Bear Lake watershed area, with an average flow of roughly 2600 AF for the 14-year period.

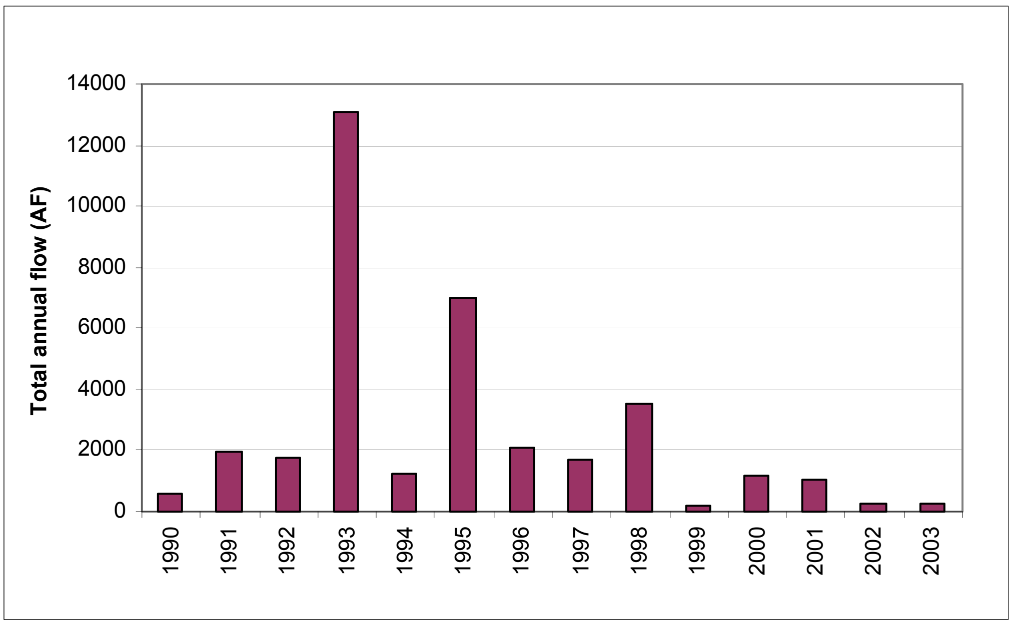

Figure 4-3: Total annual simulated flow from HSPF land uses for Rathbun Creek 1990-2003 (CY))

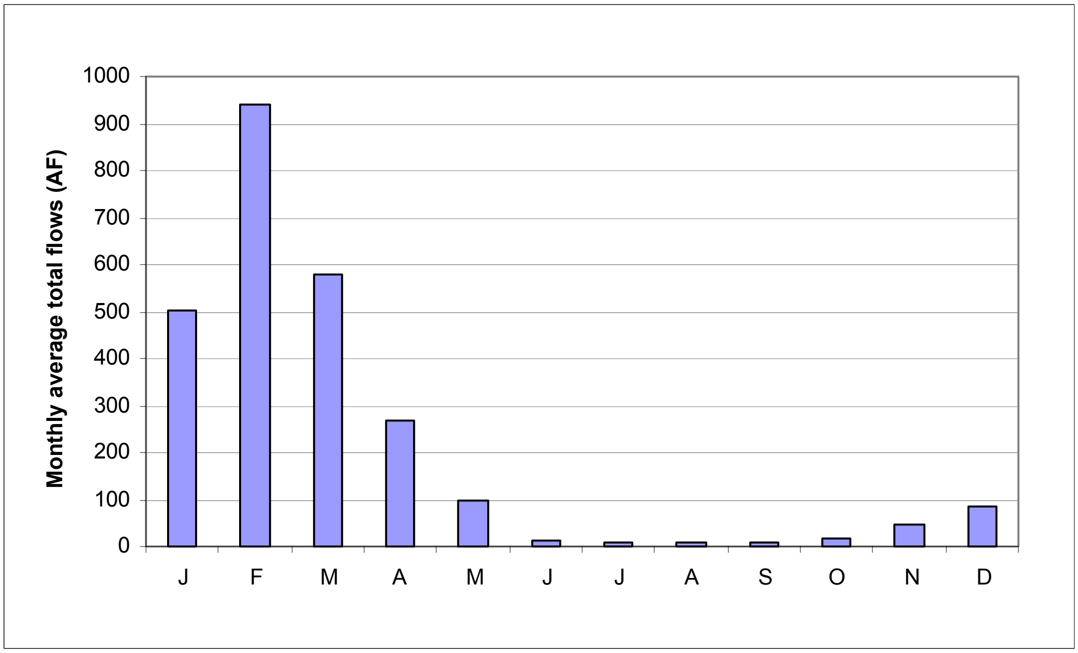

Figure 4-4: Monthly trends of average total flow for Rathbun Creek, 1990-2003 (CY)

4.1 Loads from Forest, Resort and Urban land uses

Big Bear Lake

Sediment produced by land surface erosion for pervious land segments was simulated by the SEDMNT module section in HSPF. Subroutine SOSED2 was used to simulate the washoff of detached sediment and the scouring of the soil matrix. The washoff process involves the detachment of sediment from the soil matrix, the attachment of sediment to the soil matrix, and the transport of this sediment (Bicknell et al. 2001, 88). Rainfall splash causes the detachment of sediment. Overland flow transports the detached sediment. Attachment of sediment to the soil matrix only occurs on days without rainfall (Bicknell et al. 2001, 88). Sediment loads were obtained for the Big Bear Lake watershed from the four land uses (forest, resort, residential, and high density urban), each of which has pervious and impervious areas. To reiterate, the following ratios were used to determine the percentage of impervious/pervious area for each land use: forest north (0.5%, 99.5%); forest south (0.5%, 99.5%); resort (5%, 95%); residential (15%, 85%); and high density urban (50%, 50%). The model set-up used the default value of 1.0 for the Supporting Management Practice Factor (SMPF), which is used to simulate the reduction in erosion achieved by use of erosion control practices. The default value of 1.0 assumes that there is no erosion control implemented on the various land uses. Whether or not this represents actual conditions in the watershed will be evaluated as part of the source assessment that is part of a Proposition 13 grant.

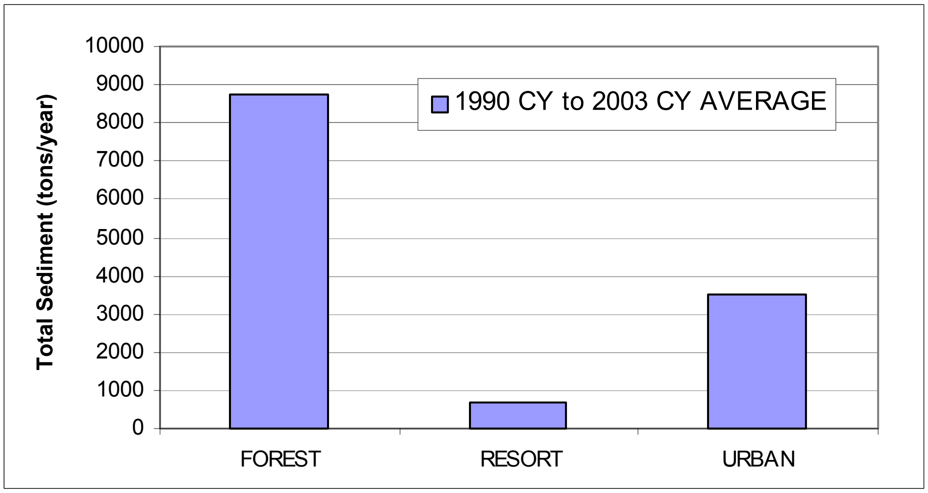

Figure 4-5: Average annual simulated sediment loads from land uses for 14 years (1990-2003)

Annual total sediment loads to Big Bear Lake simulated by the HSPF model for 1990 to 2003 are shown in Table 4-2. The largest sediment load, 64,882 tons, for the last 14 years (1990-2003) was calculated for 1993, which also corresponded to the wettest year and the greatest external inflows. Total sediment loads for the last 5 years (1999-2003) averaged 4,096 tons per year (Table 4-2). The annual average load during the 14-year period, 1990-2003, is more than 3 times the annual average load for the period of record from 1999-2003. The difference in the annual average load for these two time spans is attributed to the wet hydrological conditions that occurred in 1993, 1995, and 1998, although a recent study conducted by Kirby (2005) suggests that changing lake levels and not major storm events, such as those that occurred in 1993, contributes the majority of sediment to the lake (see footnote 21 on page 48). Runoff from forest areas contributed 68% of the total average sediment load for the 14 period (1990-2003), while runoff from resort areas contributed 5% and urban areas contributed 27%. These loads are depicted in Figure 4-5 and tabulated and summarized in Table 4-3.

Note that sediment loads from impervious areas of the four land uses are not included in the total pervious sediment loads. The total sediment loads summarized in Table 4-2 include only the fraction from pervious land uses, although dry atmospheric deposits, street deposition, and organic litter would be expected to build up on the impervious land surfaces. Rainfall would allow these sources to wash off into the receiving bodies of water due to the reduced ability of water to infiltrate into the ground. The volume of runoff from the various land surfaces drives the sediment loads from impervious land surfaces.

Table 4-2 HSPF simulated annual sediment loads to Big Bear Lake (CY)

CALENDAR YEAR	PRECIPITATION AT BIG BEAR LAKE DAM (IN)+	TOTAL ANNNUAL INFLOW (AF)	TOTAL SEDIMENT (TONS)
1990	22	3271	8294
1991	38	11665	7674
1992	44	9677	13496
1993	74	74610	64882
1994	32	6852	8736
1995	49	35880	23624
1996	41	10262	9525
1997	27	8742	9323
1998	50	20246	15210
1999	13	852	1741
2000	25	6254	4220
2001	31	5906	10519
2002	15	1104	2619
2003	32	1130	1379
1999-2003 AVERAGE	**23**	**3049**	**4096**
1990-2003 AVERAGE	**35**	**14032**	**12946***
MAX	74	74610	64882
MIN	13	852	1379

+Annual rainfall data are from January 1 through December 31 (*Data Source: Big Bear Municipal Water District 2004b*)
*12945.9 rounded up to 12946

Table 4-3. Total annual simulated sediment loads to Big Bear Lake from HSPF model land uses for the 14-year period, 1990-2003 (CY)

	TOTAL SEDIMENT LOADS FROM LAND USES (TONS/YEAR)			
CALENDAR YEAR	FOREST	RESORT	URBAN	TOTAL
1990	5815	449	2030	8294
1991	4962	454	2258	7674
1992	9469	720	3307	13496
1993	42985	3286	18611	64882
1994	6078	476	2181	8736
1995	15508	1091	7025	23624
1996	6688	496	2342	9525
1997	6871	459	1993	9323
1998	9914	835	4462	15210
1999	1215	113	413	1741
2000	2902	241	1076	4220
2001	7168	647	2704	10519
2002	1751	151	717	2619
2003	970	75	335	1379
1990-2003 AVERAGE	**8735.2**	**678.2**	**3532.5**	**12945.9**
% OF TOTAL AVERAGE	**68**	**5**	**27**	
MAX	42985	3286	18611	
MIN	970	75	335	
1999-2003 AVERAGE	2801	246	1049	4096
% OF TOTAL AVERAGE	68	6	26	

Rathbun Creek

Shown in Table 4-4 are the calculated external sediment loads for the period of record (1990 to 2003) for the Rathbun Creek subwatershed. Sediment loads to this tributary were not actually simulated due to the lack of monitoring data for model calibration. Instead, a ratio of subwatershed area to the total Big Bear Lake watershed area was determined for each pervious/impervious land use that occurred in the tributary watershed (see Tables 1-2 and 1-3). This percentage was then multiplied by the total sediment loads to Big Bear Lake for each land use to obtain the total sediment load for the different land uses for Rathbun Creek.

For the 14-year period 1990-2003, runoff from forest areas contributed 47% of the total average sediment load, runoff from resort areas contributed 18%, and runoff from urban areas contributed 35%. The largest sediment load, 10,908 tons, for the last 14 years (1990-2003) was calculated for 1993, which also corresponded to the wettest year and the greatest external inflows. Total sediment loads for the last 5 years (1999-2003) averaged 739 tons per year. The annual average load during the 14-year period, 1990-2003, is more than three times the annual average load for the period of record from 1999-2003. The difference in the annual average load for these two time spans is attributed to wet hydrological conditions that occurred in 1993, 1995, and 1998 (also see discussion on pages 48 and 60).

Sediment yields for the different land uses for Rathbun Creek were calculated in tons/acre/year. These yields were 0.36 for forest north, 0.86 for forest south, 0.96 for resort, 0.60 for residential, and 0.95 for high density urban.

Sediment Load by Tributary Area

In addition, the sediment yields for other tributary watersheds within the Big Bear Lake watershed were evaluated by staff (Figure 4-6). Using GIS, the percentages of each type of soil, land use, aspect and elevation were summarized for individual tributaries (Table 4-5). Based on the information in Table 4-5 and the sediment yields in Figure 4-6, some inferences about sediment yields in similar tributaries can be made. For instance, Grout Creek and Metcalf Creek have a similar composition of soils and land use and the sediment yields for Grout Creek and Metcalf Creek are also similar (0.6 tons/acre/year and 0.5 tons/acre/year, respectively). Similarly, Knickerbocker and Red Ant Creeks have a comparable composition of soils and have the same sediment yield of 0.6 tons/acre/year. Minnelusa Canyon Creek has the highest sediment yield of all the tributaries examined (0.8 tons/acre/year) and is comprised almost completely of the Lithic Xerothents-Lizzant (FrF) soil units. As shown in Figure 1-11, the areas in which the highest erosion potential exists are those areas in which the slopes are steepest and are comprised of the DaE, FrF or MbF soil units. From this, it would appear that Boulder Creek and Minnelusa Canyon Creek are within the high erosion category. Grout Creek and Metcalf Creek have similar percentages of DaE, while Rathbun Creek's combined percentage of the DaE and FrF soil units consists of a little more than a third of the total. Although Rathbun Creek was placed on the 303(d) list for sedimentation, it appears based on this evidence that other creeks (i.e., Minnelusa Canyon Creek, Grout Creek) might contribute greater sediment loads to Big Bear Lake than Rathbun Creek. To verify the simulated sediment load from Minnelusa Canyon Creek and other creeks, the creeks should be field checked and monitored as part of the watershed-wide monitoring proposed for this TMDL (see Attachment A).

Table 4-4. Total annual simulated sediment loads to the Rathbun Creek subwatershed from HSPF model land uses for the 14 year period, 1990-2003 (CY)

	TOTAL SEDIMENT LOADS FROM LAND USES (TONS/YEAR)			
CALENDAR YEAR	FOREST	RESORT	URBAN	TOTAL
1990	728	272	503	1503
1991	515	275	542	1333
1992	1321	436	818	2576
1993	4838	1991	4078	10908
1994	772	289	539	1600
1995	2290	661	1508	4459
1996	916	300	566	1783
1997	1068	278	485	1831
1998	1312	506	1023	2841
1999	109	69	103	280
2000	445	146	247	838
2001	839	392	674	1905
2002	162	92	176	430
2003	115	45	82	243
1990-2003 AVERAGE	**1102.3**	**410.9**	**810.3**	**2323.5**
% OF TOTAL AVERAGE	**47**	**18**	**35**	
MAX	4838	1991	4078	10908
MIN	109	45	82	243
1999-2003 AVERAGE	334	149	256	739
% OF TOTAL AVERAGE	45	20	35	

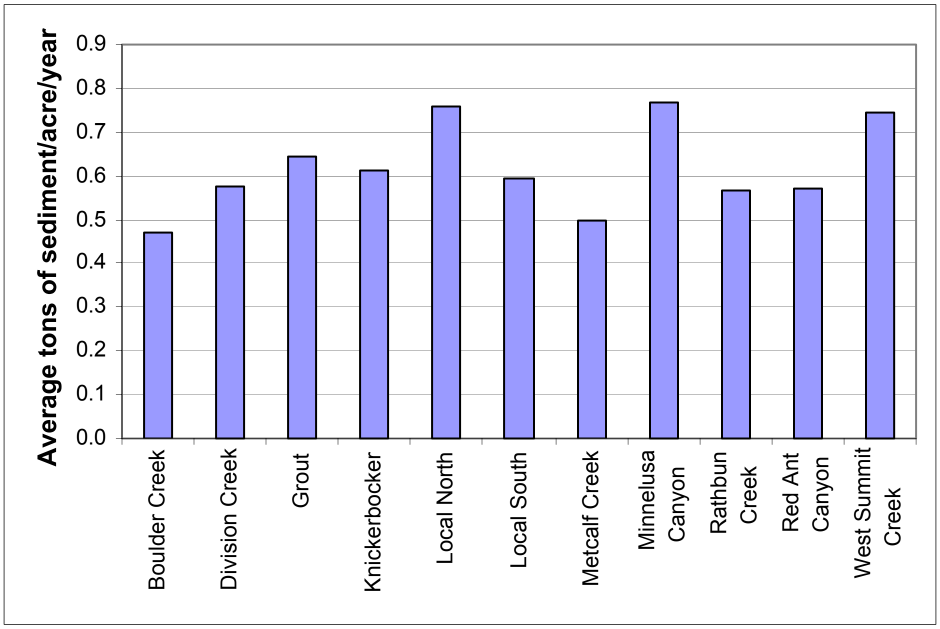

Figure 4-6. Estimated average sediment yield for selected tributaries within the Big Bear Lake watershed

Table 4-5. Relative percentages of soil family, mean annual precipitation, land use type and aspect/elevation for selected Big Bear Lake tributaries

	Soil Family					Mean Annual Precipitation					Land Use Type				Aspect/elevation			
Tributary Name	DdDE	DaE	BoD	FbE	FrF	<20"	20-25"	25-30"	30-35"	>35"	Forest	Resort	Residential	High Density Urban	South <7400	South >7400	North <7400	North >7400
Boulder Creek	23	77	0.3					31	69		100				5	16	17	61
Division Creek		3	97			100					36		61	3	23		77	
Grout Creek	58	33	9			17	61	15	5	3	96		3.6	0.5	38	19	24	19
Knickerbocker Creek	74		18	8			13	60	28		67	11	6	15	6	13	38	42
Metcalf Creek	49	47	4				1	40	59		96		2	2	5	19	28	48
Minnelusa Canyon Creek			3		97	10	42	47			90		10		41	45	8	7
Rathbun Creek		15	36	27	21	24	32	32	13		60	10	25	5	13	10	35	42
Red Ant Creek	69		31				14	63	23		79	9	2	9	10	10	45	35
Summit Creek			55	45		30	25	40	5		19	30	32	19	4	2	64	30

Notes: Soil family descriptions: DdDE = Pacifico-Preston; DaE = Pacifico-Wapi; BoD = Morical-Hecker; FbE = Merkel-Switchback; FrF = Lithic Xerothents-Lizzant